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A Search for "Dwarf" Seyfert Nuclei. V. Demographics of Nuclear Activity in Nearby Galaxies

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ABSTRACT

We use the sample of emission-line nuclei derived from a recently completed optical spectroscopic survey of nearby galaxies to quantify the incidence of local ($z \approx 0$) nuclear activity. Particular attention is paid to obtaining accurate measurements of the emission lines and reliable spectral classifications. The resulting data base contains the largest collection of star-forming nuclei and active galactic nuclei (AGNs) currently known for nearby galaxies. It consists of 420 emission-line nuclei detected from a nearly complete, magnitude-limited sample of 486 galaxies with $B_T \leq 12.5$ mag and declination $> 0°$; the equivalent-width detection limit of the brightest emission line, usually Hα, is ~0.25 Å.

Consistent with previous studies, we find detectable amounts of ionized gas in the central few hundred parsecs of most (86%) galaxies; emission lines are present in essentially every spiral galaxy and in a large fraction of ellipticals and lenticulars. Based on their narrow-line spectra, half of the objects can be classified as H II or star-forming nuclei and the other half as some form of AGN, of which we distinguish three classes — Seyfert nuclei, low-ionization nuclear emission-line regions (LINERs), and transition objects which we assume to be composite LINER/H II-nucleus systems. The population of AGNs consequently is very large; approximately 43% of the galaxies in our survey can be regarded as "active," although, for a number of reasons, this

[1]Present address.

fraction is still rather uncertain. Most of the objects have much lower luminosities than AGNs commonly studied; the median luminosity of the narrow Hα line, after correcting for extinction, is only 2×10^{39} ergs s^{-1}. Our sample therefore occupies the extreme faint end of the AGN luminosity function.

We detect signatures of a broad-line region, as revealed by visible broad Hα emission, in ∼20% of the AGN sample. Seyfert nuclei, both type 1 and type 2, reside in ∼10% of all galaxies. LINERs make up the bulk (1/2–3/4) of the AGN population and a significant fraction (1/5–1/3) of all galaxies. A nonnegligible subset of LINERs emit broad Hα emission, furnishing direct evidence that at least some LINERs are indeed related physically to the AGN phenomenon.

The dominant ionization mechanism of the nuclear emission depends strongly on the morphological type and luminosity of the host galaxy. AGNs are found predominantly in luminous, early-type (E to Sbc) galaxies, while H II nuclei prefer less luminous, late-type (Sbc and later) systems. The various AGN subclasses have broadly similar host galaxies.

Subject headings: galaxies: active — galaxies: nuclei — galaxies: Seyfert — galaxies: starburst — surveys

1. Introduction

Emission-line spectroscopy of the central regions of galaxies can yield information often inaccessible through other observational techniques. Optical emission lines in particular trace the warm, ionized component of the interstellar medium. In addition to providing information on the nebular conditions and kinematics of the line-emitting material, the emission lines, as reprocessed radiation, can potentially probe the physical mechanism responsible for the ionization of the gas. The presence of optical and ultraviolet emission lines in galaxy nuclei is often taken to be a sign of nuclear "activity," and spectroscopic surveys, especially at optical wavelengths, have become a widely practiced means of gathering large samples of emission-line nuclei for a variety of statistical studies.

One particular application has been to investigate the nature of the line emission in the central regions of nearby galaxies. Over the last two decades, a number of spectroscopic surveys of nearby galaxies have been conducted for this purpose (Heckman, Balick, & Crane 1980; Heckman 1980b; Stauffer 1982a, b; Keel 1983a, b; Phillips et al. 1986; Véron & Véron-Cetty 1986; Véron-Cetty & Véron 1986). One of the principal results of these studies is the realization that the incidence of nuclear activity, possibly nonstellar in origin, appears to be very high. Heckman (1980b) identified low-ionization nuclear emission-line regions (LINERs) as major constituents of the extragalactic population, particularly among early-type galaxies. The optical emission-line spectra of LINERs broadly resemble those of traditional active galactic nuclei (AGNs) such as Seyfert nuclei, but they

have characteristically lower ionization levels. The physical nature of LINERs has been the subject of considerable debate (see Filippenko 1996 for a recent review), but one viable interpretation is that they are simply another manifestation of the AGN phenomenon. If true, LINERs would heavily populate the faint end of the local luminosity function of AGNs, with consequences for a range of astrophysical issues. In this paper we assume that LINERs are indeed genuine AGNs.

Not all emission-line nuclei require an exotic source of ionizing radiation. A sizable fraction of the objects have spectra similar to those of giant extragalactic H II regions, and their primary ionization mechanism must be photoionization by ultraviolet radiation from young, massive stars. This population offers insights into the process of star formation in an environment that is likely to be substantially different from that of galactic disks.

The above-mentioned surveys, while tremendously valuable in establishing the qualitative patterns of nuclear activity among nearby galaxies, suffer from several shortcomings that make quantitative applications uncertain. At optical wavelengths the nuclear component of a typical nearby galaxy is generally much weaker than the stellar background of its bulge. Thus, in addition to having small fluxes and sometimes being blended together, the emission lines are diluted by stellar absorption lines, necessitating careful removal of the starlight contamination for accurate measurements. As discussed by Ho (1996), this crucial step in the analysis was not always treated adequately in many of the older studies.

We recently completed an extensive spectroscopic study of the nuclear regions of nearly 500 bright, northern galaxies. This survey contains the largest published data base of homogeneous and high-quality optical spectra of nearby galaxies; it represents a significant improvement, both in sample size and in sensitivity, compared with previous studies of its kind. We have invested substantial effort to correct the spectra for starlight contamination in a consistent and objective fashion. In addition to being able to detect much fainter emission lines than has been possible in the past, we believe that our emission-line measurements are quantitatively much more reliable. This distinction directly impacts the accuracy of the spectral classification, with ramifications for all ensuing analyses that make use of the statistics of the various classes of emission-line nuclei.

The purpose of this paper is to summarize the demographics of emission-line nuclei in light of these new data. Specifically, we report on the detection rates of star-forming nuclei and of various subclasses of AGNs, and we examine the dependence of their detection rates and number distributions on the morphological type and luminosity of the host galaxies. The likely influence of selection biases and sample incompleteness are discussed. Some general statistical properties of the sample are additionally noted.

2. The Palomar Survey

The analysis in this paper is based on a magnitude-limited survey of 486 northern galaxies. The sample is defined to be all galaxies listed in the Revised Shapley-Ames Catalog of Bright

Galaxies (RSA; Sandage & Tammann 1981) with $\delta > 0^\circ$ and $B_T \leq 12.5$ mag, with a few minor alterations as described by Ho, Filippenko, & Sargent (1995, hereafter Paper II). The data base consists of high-quality optical spectra of moderate resolution (100–200 km s^{-1}) acquired with the Hale 5 m telescope at Palomar Observatory (Filippenko & Sargent 1985, hereafter Paper I). The selection criteria of the survey ensure that the sample is a fair representation of the local ($z \approx 0$) galaxy population, at least for high-surface brightness systems, and the proximity of the objects enables fairly good spatial resolution to be achieved. We employed a long slit of width $2''$ and adopted an extraction width of $4''$, which projects to an aperture with linear dimensions $\sim 200 \times 400$ pc^2 for the typical distances of the sample galaxies (18 Mpc; Table 1).[2] Paper II presents the spectral atlas of the survey and discusses the observational parameters and data reduction; Paper III (Ho, Filippenko, & Sargent 1997a) gives the line measurements, object classifications, and details of our treatment of starlight subtraction; Paper IV (Ho et al. 1997e) highlights the nuclei showing broad Hα emission; and Paper VI (Ho, Filippenko, & Sargent 1997b) provides a comparative analysis of the various AGN subclasses. Additional papers in this series (Ho, Filippenko, & Sargent 1997c, d) analyze the subsamples of star-forming nuclei and barred galaxies. All quantities used in this study are drawn from Paper III.

The classification system used throughout our survey parallels closely the methodology of Veilleux & Osterbrock (1987). As explained in Paper III, this system adopts a set of spectroscopic criteria that depends entirely on the line-intensity ratios of several prominent, narrow, optical emission lines. We distinguish four subclasses of emission-line nuclei: H II nuclei, Seyfert nuclei, LINERs, and transition objects. H II nuclei have spectra closely resembling those of H II regions and therefore are assumed to be powered through photoionization by young, massive stars. The other three groups represent variants of AGNs. The composite characteristics of the spectra of transition objects suggest that they are LINER nuclei contaminated by emission from neighboring H II regions (Ho, Filippenko, & Sargent 1993; Ho 1996); this hypothesis is explored further in Paper VI, where we demonstrate that transition objects and regular LINERs have strikingly similar global and nuclear properties, suggesting that they share a common physical origin. However, it should be borne in mind that the available data cannot yet unambiguously exclude alternative explanations that do not invoke nonstellar processes. In the following discussion, we will explicitly assume that transition objects indeed contain LINER nuclei, and hence that they are AGNs, although we will point out how the results would be affected if this assumption were to be relaxed. When there is a need to distinguish regular LINERs from composite sources, we will refer to the former as "pure LINERs" and to the combined sample of pure LINERs and transition objects as "all LINERs." Finally, all three classes of AGNs can host a broad-line region, as evidenced by the presence of broad Hα emission (Paper IV). Following the convention of Papers III and IV, we extend the "type 1" and "type 2" designations of Seyfert galaxies (Khachikian & Weedman 1974) to include LINERs and transition objects.

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[2]We adopt $H_0 = 75$ km s^{-1} Mpc^{-1} in this series of papers.

3. Detection Rates of Emission-Line Nuclei

The incidence of emission-line nuclei is very high in our sample (Table 2*a* and top panel of Fig. 1*a*). Integrated over all Hubble types, 86% of the nuclei have emission lines down to an equivalent-width detection limit of ∼0.25 Å (3 σ). The detection rate among spirals alone is even higher: essentially all (98%) of the galaxies classified as S0/a and later have emission-line nuclei, to be compared with 54% for the ellipticals and 64% for the lenticulars. Among the group of 66 galaxies with pure absorption-line spectra, only 8 are not classified as ellipticals or lenticulars. In a sample of disk systems with Hubble types ranging from S0/a to Scd, but with a brighter limiting magnitude ($B_T \leq 12.0$ mag), Keel (1983a) also found that essentially every object has detectable emission lines within an 8″ circular aperture. Because the sensitivity of the Palomar survey is much higher than that of Keel, we are able to achieve a comparably high detection rate for this range of morphological types, even though our effective aperture (8 arcsec^2) is six times smaller and our survey limit fainter. The Hubble type distributions of the surveys of Heckman et al. (1980) and Véron-Cetty & Véron (1986) more closely match that of the present sample, and, in these, the detection rate was only ∼60%–65%. The near ubiquity of emission lines in the nuclear spectra implies that the central 200–400 pc of most galaxies, including those of early type, contain detectable amounts of warm ($\sim 10^4$ K) ionized gas. The typical Hα luminosity of $\sim 1\times10^{39}$ ergs s^{-1} (§ 6) and electron density of 200 cm^{-3} (Paper VI; Ho et al. 1997c) translate to an ionized hydrogen mass of $\sim 2\times10^4$ M$_\odot$.

The two categories of nuclear activity (stellar and nonstellar) occur with nearly equal frequency among galaxy nuclei. Approximately half of the emission-line objects (42% of all galaxies) are classified as H II nuclei, and the other half belongs to the AGN group (43% of all galaxies); the proportion becomes 56% H II nuclei and 30% AGNs if we reassign transition objects to the former group. While the incidence of both varieties of nuclear activity is widespread among galaxies of all morphologies, each depends strongly and differently on the Hubble type of the host (middle and bottom panels of Fig. 1*a*). H II nuclei clearly prefer late-type hosts, whereas AGNs prefer early-type hosts. Some overlap occurs between the two distributions, but they segregate roughly at a Hubble type of Sbc: 82% of galaxies later than Sbc have H II nuclei, and 60% of galaxies earlier than Sbc have AGNs. Surprisingly, not a single elliptical galaxy in our sample shows detectable nuclear emission attributable to star formation, in stark contrast to the substantial fraction of AGNs that contribute to this morphological bin (∼50%). This is consistent with the survey of early-type (E and S0) galaxies of Phillips et al. (1986); the few objects they identified as having H II nuclei are all classified S0 (two are E-S0). Signatures of nonstellar ionization, on the other hand, do exist in a minority of late-type hosts; roughly 15% of the Sc, Sd, and Sm galaxies, and 40% of the amorphous systems (I0) contain AGNs (but there are only five amorphous galaxies in our sample, so the latter statistic should be treated with caution).

4. Subclasses of AGNs

All three subclasses of AGNs show similar detection rates as a function of Hubble type (Fig. 1*b*). The most conspicuous differences are that (a) pure LINERs, compared to Seyferts, are seen in a higher fraction of ellipticals and, (b) among all LINERs, the transition group is detected more frequently in galaxies of somewhat later Hubble types. Approximately 10% of the survey sample contain Seyfert nuclei; this doubles the figures estimated in previous studies (Stauffer 1982b; Keel 1983b; Phillips, Charles, & Baldwin 1983; Maiolino & Rieke 1995). Note that the Seyfert nuclei in our sample do not exclusively reside in spirals, as is usually thought (e.g., Adams 1977; Weedman 1977). Pure LINERs are present in ∼19% of all galaxies, and transition objects, which by assumption also contain a LINER component, account for another ∼13%. Thus, LINERs are major constituents of the galaxy population — they reside in 1/3 of all galaxies brighter than B_T = 12.5 mag. Because of the strong preference for early-type hosts, the detection rate approaches 50% for galaxies of types E–Sbc. If all LINERs can be regarded as genuine AGNs, they make up the bulk of the AGN population (75%) in the luminosity range probed by our survey, outnumbering Seyferts two to one.

A sizable fraction of the AGN sample (∼20%) shows broad Hα emission, presumably arising from the conventional broad-line region (Paper IV). The broad emission is generally very weak and difficult to measure; consequently, most of the objects identified in our survey have previously been unrecognized. Of the 46 detections reported in Paper IV, only 22 formally have a Seyfert classification, and the remaining 24 fall in the LINER group (22 LINERs and 2 transition objects). We proposed in Paper IV that the "type 1/type 2" designations, traditionally used to distinguish between Seyfert nuclei with and without a visible broad-line region, respectively, be extended to include LINERs and transition objects. The number ratio of type 2 to type 1 Seyferts in our survey is 1.4 to 1; the corresponding ratio for pure LINERs is 3.3 to 1, and for all LINERs (including transition objects) it is 5.6 to 1. As discussed in Paper IV, we suspect that selection effects severely hamper the detection of broad Hα in transition objects, thereby leading to an apparently low incidence of type 1 objects in this group. It is possible that the true frequency of type 1 transition objects is as high as that of type 1 pure LINERs.

5. Trends with Galaxy Morphological Type and Integrated Luminosity

The distribution of morphological types in Figure 2*a* illustrates that H II nuclei reside most frequently in Sc galaxies [median T = 5.0, where T is the numerical Hubble type index as defined by de Vaucouleurs (1959, 1963)], and most AGNs cluster toward early-type disks systems (S0–Sbc; median T = 1.0, corresponding to Sa). The three AGN subclasses once again show very similar distributions of host galaxy types (Fig. 2*b*). LINERs and Seyferts have virtually indistinguishable host galaxy types (aside from a higher proportion of ellipticals among LINERs), an important clue to the physical nature of LINERs (Paper VI).

The frequency of bars among the emission-line objects is identical to that of the entire sample of disk systems in the survey (56%; Paper III), since most of the absorption-line objects are ellipticals. The bar fraction of the H II nuclei hosts (62%) does not differ appreciably from that of the AGN hosts (49%), which itself remains constant among the AGN subclasses. However, as discussed more fully by Ho et al. (1997d), the presence of a bar does enhance the probability and intensity of nuclear star formation in spiral galaxies. Such an effect is not seen among the AGN hosts.

Because early-type galaxies on average tend to be more luminous compared to late-type galaxies (e.g., Roberts & Haynes 1994), the trends perceived with Hubble type translate into similar patterns in total galaxy luminosity. The distributions of absolute blue magnitudes, corrected for internal extinction ($M^0_{B_T}$; Paper III), are shown in Figure 3*a*. The hosts of H II nuclei clearly have lower luminosities than the hosts of AGNs, being fainter than the latter by $\sim$0.5 mag in their median $M^0_{B_T}$ (–20.01 mag versus –20.46 mag). The cumulative distributions of the two samples are significantly different according to the Kolmogorov-Smirnov test (Press et al. 1986); the probability that the two distributions are drawn from the same population ($P_{\rm KS}$) is 5.7×10^{-4}.

Interestingly, the objects lacking emission-line nuclei are noticeably less luminous (median $M^0_{B_T}$ = –19.56 mag) than those containing either H II nuclei or AGNs. Since almost all of the absorption-line objects are ellipticals and lenticulars, a fair comparison sample should be restricted to have the same range of Hubble types. The sample of emission-line objects classified as E and S0 has a significantly higher median luminosity than the absorption-line objects ($\Delta M^0_{B_T}$ = 0.66 mag; $P_{\rm KS}$ = 0.0046). The difference remains even after excluding the two extremely low-luminosity dwarf elliptical galaxies (NGC 147 and NGC 205) from the absorption-line sample. The availability of gas, a necessary condition for the generation of emission lines, somehow appears to depend on the total luminosity, and presumably mass, of the galaxy. We are tempted to speculate that the supply of gas is linked to the mass of the stellar component, possibly via mass loss from evolved stars.

The homogeneity noted in the morphologies of the host galaxies of the AGN subclasses becomes even more striking when we examine their absolute magnitudes (Fig. 3*b*). Apart from a slight excess of low-luminosity objects among the transition objects, all three AGN groups have similar distributions of absolute magnitudes; any minor differences among them have no formal statistical significance. It is again noteworthy that LINERs and Seyferts both peak at $M^0_{B_T} \approx$ –20.5 mag, about 0.4 mag brighter than $M^*_{B_T}$, the typical absolute magnitude of the field-galaxy luminosity function (e.g., Kirshner, Oemler, & Schechter 1979, after adjusting to our adopted H_0 = 75 km s^{-1} Mpc^{-1}).

6. Strengths of the Emission Lines

Although the emission-line properties of the AGN and H II-nuclei samples are discussed in separate publications (Paper VI; Ho et al. 1997c), here we will comment briefly on the strengths of the emission lines. In general, the line emission of the objects in the Palomar survey is quite feeble. A wide range of equivalent widths is found, but the median value for the Hα line is only 5 Å (Fig. 4). H II nuclei have significantly higher emission-line equivalent widths than AGNs [median EW(Hα) = 18 Å versus 2 Å]. The marked contrast in equivalent widths between the two classes of nuclei arises not because of intrinsic luminosity differences, but rather because of the great disparity between the nuclear (stellar) continuum strengths of the two types of host galaxies. Late-type galaxies, the preferred hosts of H II nuclei, have fainter, smaller bulges than early-type galaxies, the dominant hosts of AGNs. The extinction-corrected Hα luminosities of H II nuclei are in fact larger than those of the AGN sample (Fig. 5), but the difference is only a factor of two [median L(Hα) = 1.8×10^{39} ergs s^{-1} versus 8.5×10^{38} ergs s^{-1}], whereas the difference in the equivalent widths of the two groups amounts to a factor of nine. The variation of the emission-line equivalent width with galaxy type and luminosity is illustrated in Figure 6, where the steady rise of the relative line strength toward galaxies with later Hubble types and lower luminosities is quite apparent. By contrast, the line luminosity actually decreases in late-type and low-luminosity galaxies (Fig. 7).

The majority of the H II nuclei in our survey are experiencing only modest levels of current star formation. Indeed, the typical Hα luminosity does not greatly exceed that of many individual giant H II regions, and the inferred current star-formation rates certainly are not unusual. Thus, we have resisted calling these objects "starburst" nuclei like those of Balzano (1983). Similarly, the AGNs considered here have unspectacular luminosities when compared to traditionally studied Seyferts such as those selected from the Markarian survey. The Seyferts in the compilation of Dahari & De Robertis (1988), for instance, have typical line luminosities ranging from two to three orders of magnitude larger than those in our survey. Our sample, therefore, contains mainly *low-luminosity* or "dwarf" AGNs.

7. Completeness and Selection Effects

The completeness of the overall Palomar survey is very close to that of a sample limited to $B_T \leq 12.5$ mag in the RSA, from which our sample was drawn. A discussion of the completeness of the RSA can be found in Sandage, Tammann, & Yahil (1979). Here we wish to consider the completeness of the different types of emission-line objects with respect to the parent population. A simple way to examine this issue is to compare the distribution of apparent magnitudes of the different subsamples with that of the parent sample. From Figure 8*a*, it is evident that the parent sample and the sample of H II nuclei hosts have very similar distributions of B_T ($P_{\rm KS}$ = 0.13), indicating that the latter is not incomplete relative to the former. The AGN sample, on

the other hand, has a marginally brighter B_T distribution than the parent sample ($P_{\rm KS}$ = 0.043). This arises not because the AGN sample has on average smaller distances (see below), but rather because it is comprised mainly of more luminous, early-type galaxies (§ 5). The AGN sample, therefore, suffers from some incompleteness with respect to the parent sample, although the effect seems to be slight. On closer inspection, it appears that most of the difference can be attributed to the group of pure LINERs alone (Fig. 8*b*).

To assess how the detection rates presented thus far would be modified by the relative incompleteness of the different types of nuclei, we chose subsamples with various brighter apparent magnitude limits from the parent sample, recomputed the detection rate of each group of emission-line object, and calculated the Kolmogorov-Smirnov statistic to gauge the change in completeness levels. This experiment showed that all the emission-line groups become complete with respect to the new parent subsamples at $B_T \approx$ 12.2–12.3 mag — that is to say, there is no statistically significant difference ($P_{\rm KS} >$ 0.1) in the relative distributions of B_T. The detection rates of the various types of emission-line nuclei at this new limiting magnitude, however, hardly change from those found using the original limiting magnitude. The detection rate for AGNs, and similarly for LINERs and transition objects, increases by ∼10%, that of H II nuclei decreases by the same amount, and that of Seyferts remains essentially unaltered.

Because our data were acquired using a slit of fixed angular size, the physical dimensions of the projected aperture scale linearly with the distance of the object, and distance-dependent selection biases in principle can affect our measurements. Specifically, with regard to the detection rates under consideration, two kinds of selection effects can occur. First, the detection of any line emission, regardless of its character, obviously depends on the angular dimension of the emission compared to the aperture size. For a given (low) surface brightness, the emitting material can be undetectable if it is very extended compared to the aperture, for example if the galaxy is exceptionally nearby. The object would then be considered to lack emission lines, even though it would have been recognized as an emission-line nucleus had it been placed at a distance more typical of the rest of the sample. An interesting example is M31. We failed to detect any line emission in the spectrum of its nucleus because of its proximity (0.75 Mpc), and in Paper III we classified it as an absorption-line nucleus. However, line emission of low surface brightness, extending over scales of several hundred parsecs, *does* exist in the circumnuclear regions of M31 (Rubin & Ford 1971). Moreover, Ciardullo et al. (1988) have shown that the spectrum of the gas shows enhanced [N II] $\lambda\lambda$6548, 6583 and [S II] $\lambda\lambda$6716, 6731 emission, as is typical of most AGNs (see Paper III). Heckman (1996) recently concluded that the spectrum is that of a LINER. The effect of distance, however, has a negligible bearing on our results because the absorption-line sample does not have a smaller median distance than the emission-line sample, and because the detection rate of emission-line objects is already so high (86%) that there is not much room for error.

Perhaps more worrisome is the accuracy of the *relative* detection rates among the emission-line objects. The integrated spectrum of the central region of a distant galaxy has a higher likelihood of

being contaminated by circumnuclear H II regions than a nearby one, thereby potentially biasing the AGN detection rate toward lower values among distant galaxies. However, the distributions of distances show no gross differences for the various subclasses (Figs. 9*a* and 9*b*). The H II nuclei are on average closer than the AGNs (median distance 17.1 Mpc versus 20.6 Mpc; $P_{\rm KS} = 2.6\times10^{-4}$) as a result of having lower luminosity hosts, and LINERs (both including and excluding transition objects) are marginally more distant than Seyferts (by 1–2 Mpc). In any case, it seems unlikely that such small differences in distances can lead to significant misclassifications in the mean. We reached a similar conclusion in Paper III based on analysis of the variation of the [N II] λ6583/Hα ratio with distance. Any individual object, of course, can certainly still be affected. We mentioned the case of M31 above. Rubin & Ford (1986) discussed a similar situation for the nucleus of M33.

Finally, in Figure 10 we examine the inclination angles (i) of the disk systems. The distribution of cosine i should be flat for an unbiased sample with random orientations. As discussed in Paper III, there is a deficit of edge-on systems ($i \gtrsim 70°$) in the parent sample, and this behavior is characteristic of magnitude-limited samples. Again, what is of interest here is to see if there are any differences between the total sample and each of the separate groups, as well as among the groups. None of the subsamples, with the exception of the Seyferts, show statistically different distributions of cosine i compared to the total sample. Seyferts do show a marginally significant deficit of edge-on systems ($P_{\rm KS} = 0.047$), and they are also somewhat more face-on than the combined LINER sample ($P_{\rm KS} = 0.060$). Another subtle difference is that transition objects tend to be more edge-on than pure LINERs ($P_{\rm KS} = 0.064$). Although these differences are not large, they are of relevance in understanding the physical distinctions between the AGN subclasses, and we will reconsider them in Paper VI. But, for now, we simply note that selection biases due to inclination effects do not appear to be serious.

In summary, we consider the detection rates reported in Table 2 and Figure 1, in both absolute and relative numbers, to be largely uncorrupted by incompleteness introduced either by the magnitude limit of the survey or by selection effects due to distance or inclination angle.

8. Comparison with Previous Studies

Many of the findings from the Palomar survey presented here are qualitatively similar to results from the older surveys cited in § 1. It has long been recognized that the incidence of nuclear activity, especially as evidenced by the LINER phenomenon, is widespread in the nearby galaxy population. Although it is still unclear whether all LINERs can be unequivocally associated with AGNs (Paper VI), the general consensus has been that these objects must be related to some form of activity substantially different from "normal" star formation. Furthermore, it has occasionally been pointed out that galaxies hosting H II nuclei have quite different morphological types than those containing Seyfert or LINER nuclei (e.g., Heckman 1980a; Keel 1983a; Terlevich, Melnick, & Moles 1987; Pogge 1989). Indeed, Burbidge & Burbidge (1962) drew attention to the fact that some galaxies show abnormal strengths of [N II] λ6583 compared to Hα, and they noted that such

galaxies tend to be of early type.

As discussed in § 1, the Palomar survey has greater sensitivity to weak emission lines than previous surveys of this kind. From a statistical perspective, it also contains a larger number of galaxies as well as a wider range of morphological types [see the summary of old surveys presented in Table 1 of Ho (1996)]. More importantly, however, we believe our emission-line measurements, and hence all subsequent derivations, to be *quantitatively* much more reliable. Our spectral classification, in particular, should be considerably more secure. The increased accuracy largely stems from our treatment of starlight correction. As an example of the immediate benefits to be gained, note that the previous studies rarely were able to detect the weak, but diagnostically important, [O I] λ6300 line. Our ability not only to detect, but to measure [O I] in a significant fraction of our emission-line objects (81%) has led us recognize the class of sources we call transition objects. Having access to a wider wavelength range, particularly in the blue, further allows us to better specify the classification. The surveys of Keel (1983a, b) and Phillips et al. (1986), for instance, did not include the Hβ and [O III] $\lambda\lambda$4959, 5007 lines, so they had no information on the excitation of their emission-line objects, and therefore no way to distinguish between Seyferts and LINERs. Perhaps the most dramatic improvement, however, can be seen in the high detection rate of broad Hα emission in our survey (Paper IV). This has resulted in a robust determination of the relative fraction of type 1 and type 2 AGNs, and it has shown, for the first time, that a significant fraction of LINERs contain a broad-line region, a finding that has important consequences for the longstanding debate on the physical origin of this class of objects (Paper VI).

As is well known, existing AGN samples suffer from various degrees of biases and incompleteness [see, e.g., discussion in Huchra & Burg (1992)]. The incompleteness is most severe for low-luminosity sources. The sample of Seyfert nuclei spectroscopically selected from the CfA redshift survey (Huchra & Burg 1992) is widely regarded as perhaps the least biased available set. Yet, even this sample misses many of the weak sources included in the Palomar list, and, as recognized by Huchra & Burg (1992), the CfA sample is very incomplete in its census of LINERs. Maiolino & Rieke (1995) improved the situation by tallying the Seyfert content in the RSA ($B_T < 13.4$ mag) based on spectral classifications taken from the literature. They deduced a lower limit of 5% to the frequency of Seyfert nuclei in nearby galaxies, but, based on completeness considerations, they argue that the true frequency could be as high as 16%. Their lower limit, while consistent with our results, is too low by a factor of $\sim$2, and their estimate of the true frequency appears to be somewhat high. Since Maiolino & Rieke based their study on published material, it is not surprising that they, too, missed many of the Seyferts recovered in our survey. Indeed, a significant fraction of the published classifications they used were drawn from the very studies which we evaluated relative to the Palomar survey in § 1. Only half of the 52 Seyferts in the Palomar sample appear in the tabulation of Maiolino & Rieke.

9. Concluding Summary

A large sample of emission-line nuclei has been identified in a recently completed optical spectroscopic survey of nearby galaxies, allowing several statistical properties of the host galaxies and of the line-emitting regions to be examined reliably for the first time. As a consequence of the many detections and some revised classifications, the detailed demographics of emission-line nuclei have been updated from those given in older surveys. Table 1 gives a synopsis of their main characteristics, and Table 2 summarizes the detection rates of the different object classes. This paper reports the detection rate of line emission in the central regions of galaxies, the incidence of different classes of emission-line nuclei, and their dependence on the morphological type and luminosity of the host galaxy type. The main conclusions of this paper, which are based on 420 emission-line nuclei selected from a magnitude-limited ($B_T \leq$ 12.5 mag) sample of 486 northern ($\delta > 0^\circ$) galaxies, are as follows.

(1) Consistent with previous studies, the central few hundred parsecs of most (86%) galaxies have detectable amounts of ionized gas as traced by optical emission lines. The detection rate essentially reaches 100 percent for spiral galaxies.

(2) The emission-line nuclei divide nearly equally in number between H II nuclei and AGNs, where AGNs collectively refer to Seyfert nuclei, LINERs, and transition objects (composite LINER/H II nuclei). The AGN fraction in nearby galaxies is therefore very high, on the order of 43%. Unfortunately, the incidence of galaxies harboring a central massive black hole is still quite uncertain. The AGN fraction could be considerably lower, for instance, if it turns out that many transition objects do not contain LINER nuclei, or if only a minority of LINERs are genuine AGNs. We argue in Paper VI that this is unlikely to be the case. On the other hand, very weak AGNs can be hidden by brighter nuclear H II regions, or they may contain undetectably small amounts of ionized gas, and so at least some faint objects undoubtedly must have escaped notice. Efforts to quantify these effects are in progress.

(3) Based on the relative intensities of the narrow emission lines, at least 10% of all galaxies in the present survey are classified as Seyfert nuclei (types 1 and 2).

(4) LINERs are found in 1/5 to 1/3 of all galaxies and, under the assumption that they are genuine AGNs, they constitute between 1/2 to 3/4 of the AGN population, depending on whether transition objects are excluded or included in the LINER group.

(5) Broad-lined or "type 1" AGNs make up ~20% of the AGN population and ~10% of all galaxies. Approximately half of the type 1 objects belong to the LINER category.

(6) The dominant excitation mechanism of the nuclear emission depends strongly on the Hubble type and integrated luminosity of the host galaxy. AGNs reside mainly in early-type (E to Sbc) galaxies, while H II nuclei prefer late-type (Sbc and later) systems. AGN hosts are more luminous than non-AGN hosts because early-type galaxies tend to be more luminous than late-type galaxies.

(7) The subclasses of AGNs have broadly similar distributions of host galaxy morphological types and luminosities. The only noticeable difference is that a higher proportion of pure LINERs is found in elliptical galaxies, while a higher fraction of transition objects tends to be in late-type hosts.

(8) The typical object has quite modest emission-line strengths, with Hα equivalent widths of only a few Å, and luminosities (after correcting for extinction) of $\sim 10^{39}$ ergs s^{-1}.

(9) The detection rates of the various classes of emission-line objects are unlikely to be seriously incomplete or affected by selection biases due to distance or inclination.

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Figure Captions

Fig. 1. — Detection rate as a function of Hubble type of (*a*) all emission-line nuclei, H II nuclei, and AGNs, and (*b*) the different classes of AGNs. The bins along the abscissa have the following meanings: "E" = E, "S0" = S0, "Sa" = S0/a–Sab, "Sb" = Sb–Sbc, "Sc" = Sc–Scd, "Sd" = Sd–Sdm, "Sm" = Sm–Im, "I0" = I0, and "Pec" = Pec + S pec. In this and subsequent plots, the panel labeled "all LINERs" represents the sum of pure LINERs and transition objects, and the solid histograms denote type 1 AGNs.

Fig. 2. — Distribution of morphological types for (*a*) all emission-line nuclei, H II nuclei, and AGNs, and (*b*) the different classes of AGNs. In this and subsequent histograms, the downward-pointing arrow marks the median of the distribution.

Fig. 3. — Distribution of total absolute blue magnitudes ($M^0_{B_T}$, corrected for internal extinction) for the host galaxies of (*a*) all sample objects, H II nuclei, AGNs, and absorption-line nuclei, and (*b*) LINERs, transition objects, all LINERs, and Seyferts. The bins are separated by 0.5 mag. An L_* galaxy has $M^*_{B_T} \approx -20.1$ mag.

Fig. 4. — Distribution of equivalent widths of the narrow Hα emission line for all emission-line nuclei, H II nuclei, and AGNs. The bins are separated by 2 Å, and the last bin contains all objects with EW(Hα) > 30 Å.

Fig. 5. — Distribution of luminosities of the narrow Hα emission line for all emission-line nuclei, H II nuclei, and AGNs. The luminosities in the shaded and solid histograms were corrected for Galactic and internal reddening, the latter determined from the observed Balmer decrement (see Paper III), while the observed luminosities are shown in the unshaded histogram with heavy line. The bins are separated by 0.25 in logarithmic units.

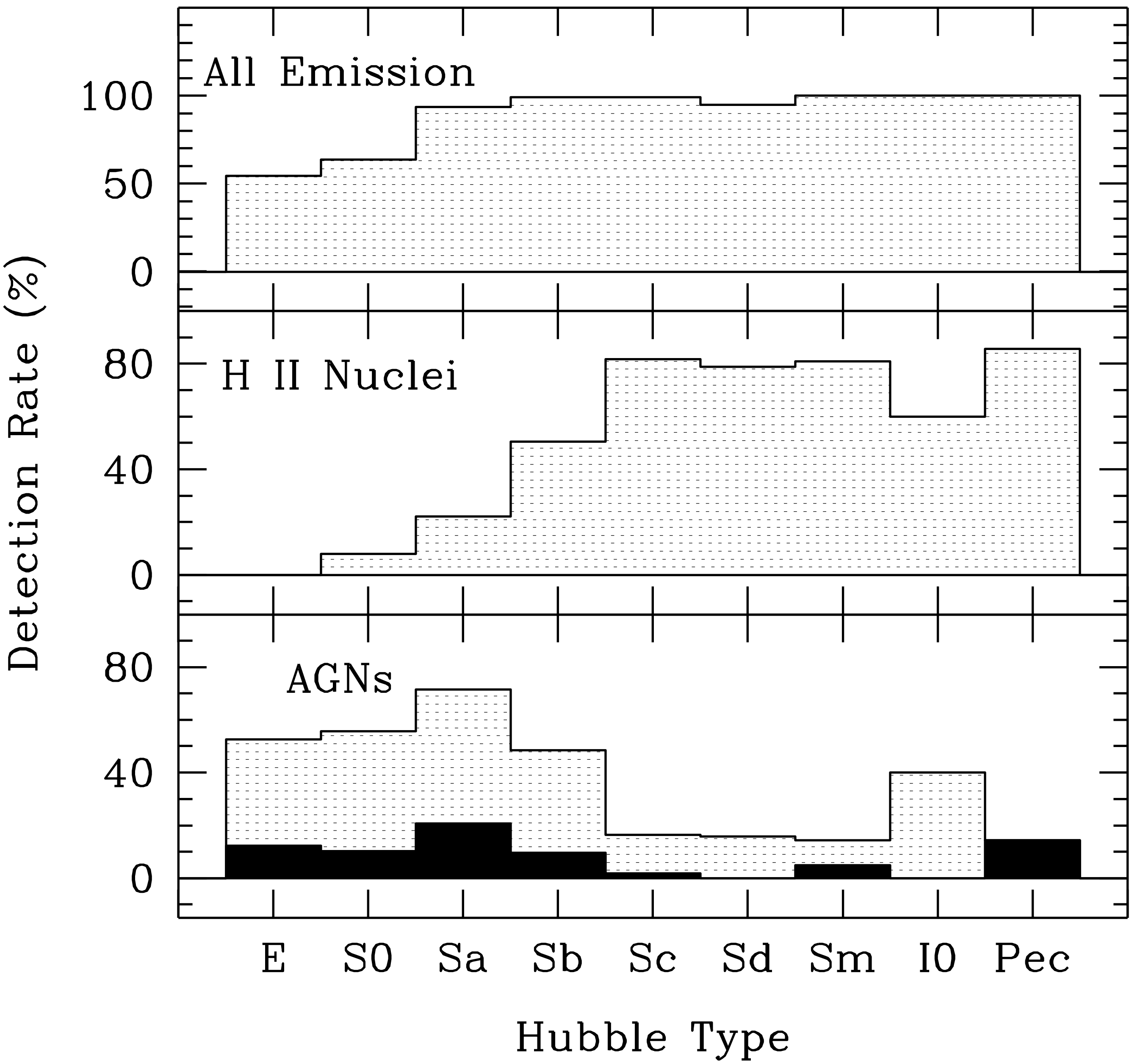
Fig. 6. — Distribution of equivalent widths of the narrow Hα emission line as a function of (*a*) the numerical Hubble type index, T, and (*b*) the total absolute blue magnitude of the galaxy, $M^0_{B_T}$. The numerical indices have the following correspondence to the Hubble sequence (see Table 12 of Paper III): –5 = E0, –3 = S0, 1 = Sa, 3 = Sb, 5 = Sc, 7 = Sd, 10 = Im, 90 = I0, and 99 = Pec or S pec. The typical uncertainty in the line measurement is illustrated by the vertical bar in the lower right corner.

Fig. 7. — Distribution of luminosities of the narrow Hα emission line as a function of (*a*) the numerical Hubble type index, T, and (*b*) the total absolute blue magnitude of the galaxy, $M^0_{B_T}$. The luminosities were corrected for Galactic and internal reddening. The typical uncertainty in the line measurement is illustrated by the vertical bar in the lower right corner.

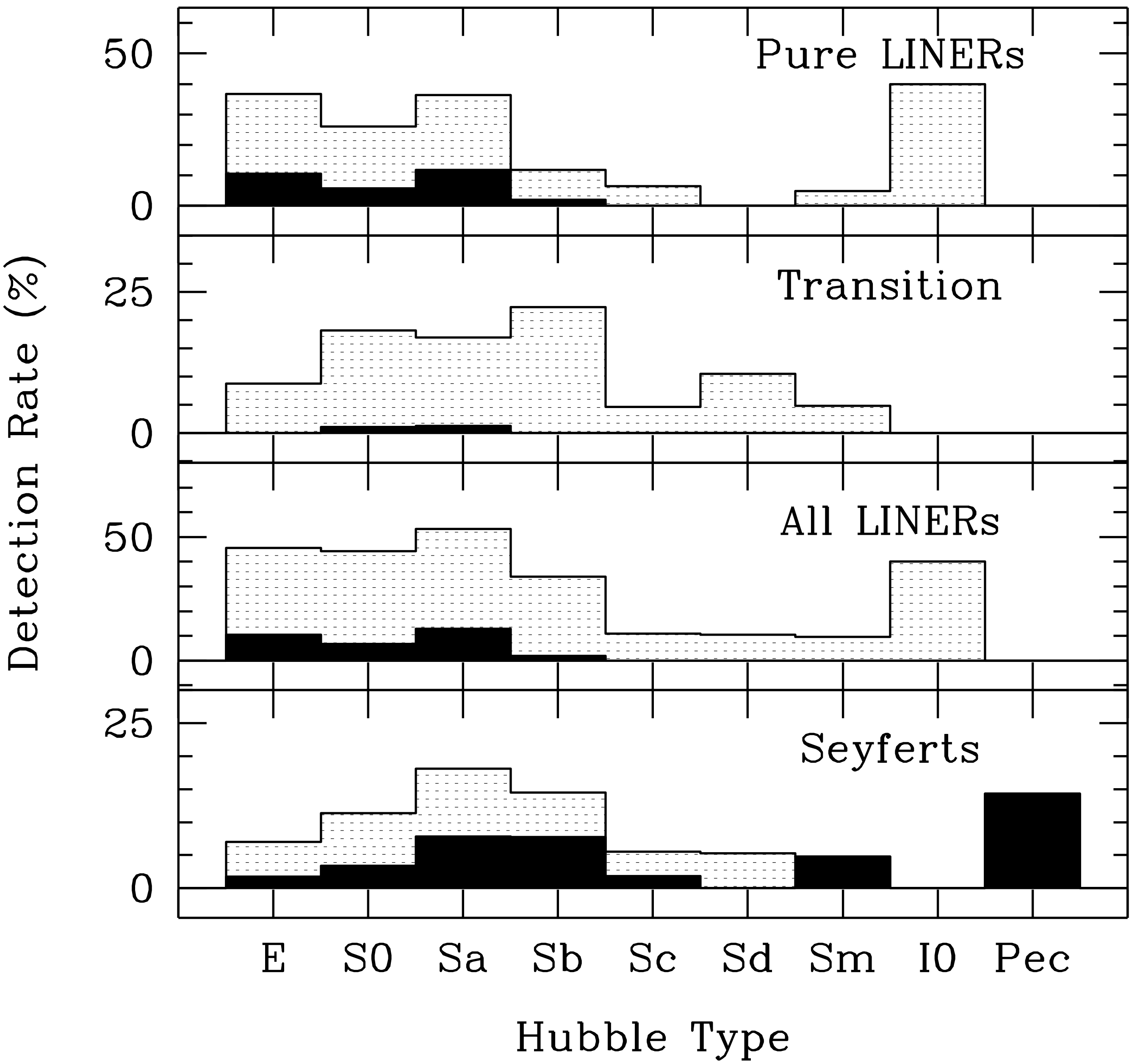
Fig. 8. — Distribution of total apparent blue magnitudes (B_T) for (*a*) all sample galaxies, H II nuclei, and AGNs, and (*b*) the different classes of AGNs. The bins are separated by 0.5 mag.

Fig. 9. — Distribution of distances for (*a*) all sample galaxies, H II nuclei, and AGNs, and (*b*) the different classes of AGNs. The bins are separated by 5 Mpc.

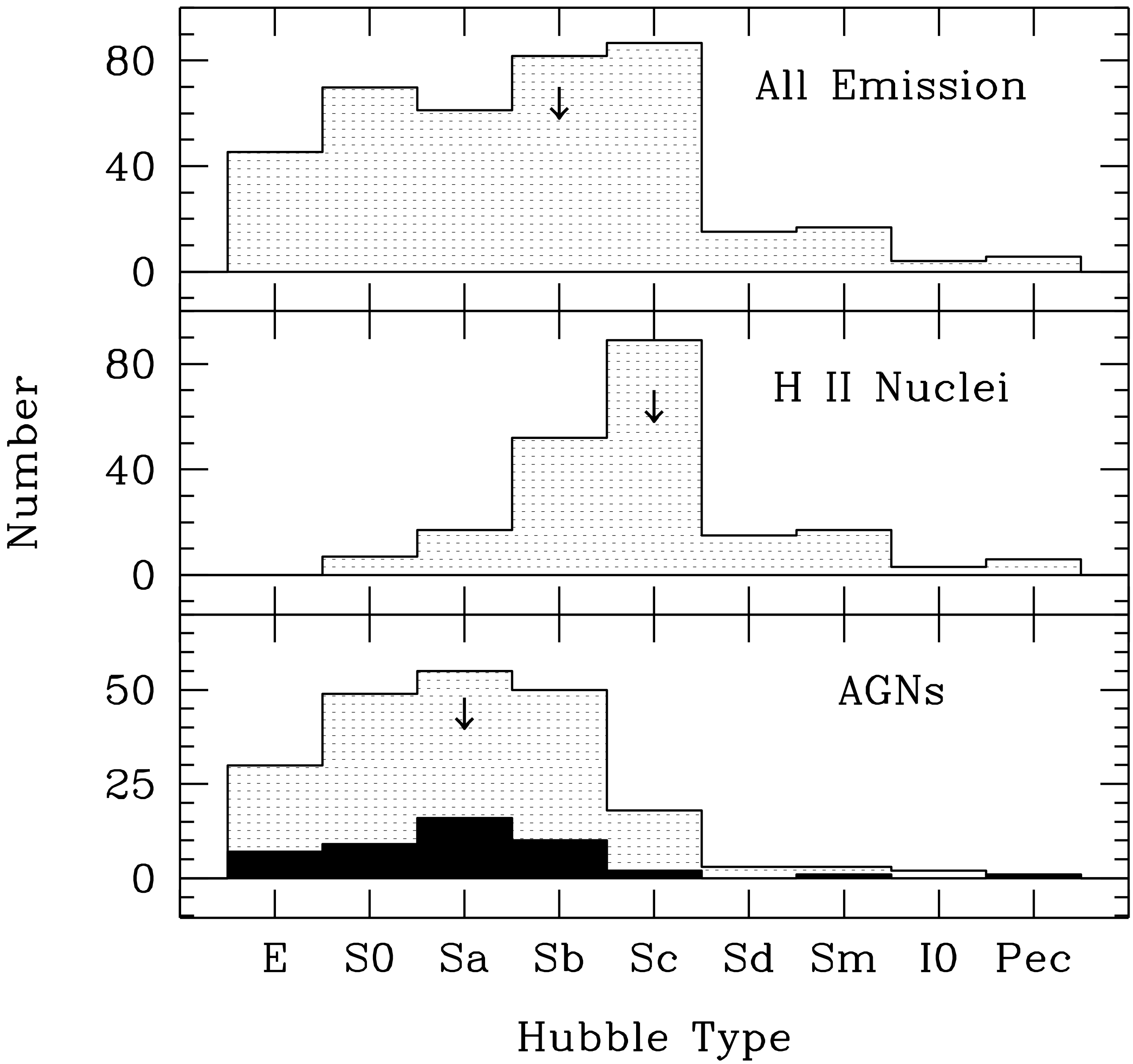
Fig. 10. — Distribution of the cosine of the inclination angle for (*a*) all sample galaxies, H II nuclei, and AGNs, and (*b*) the different classes of AGNs. The bins are separated by 0.1.



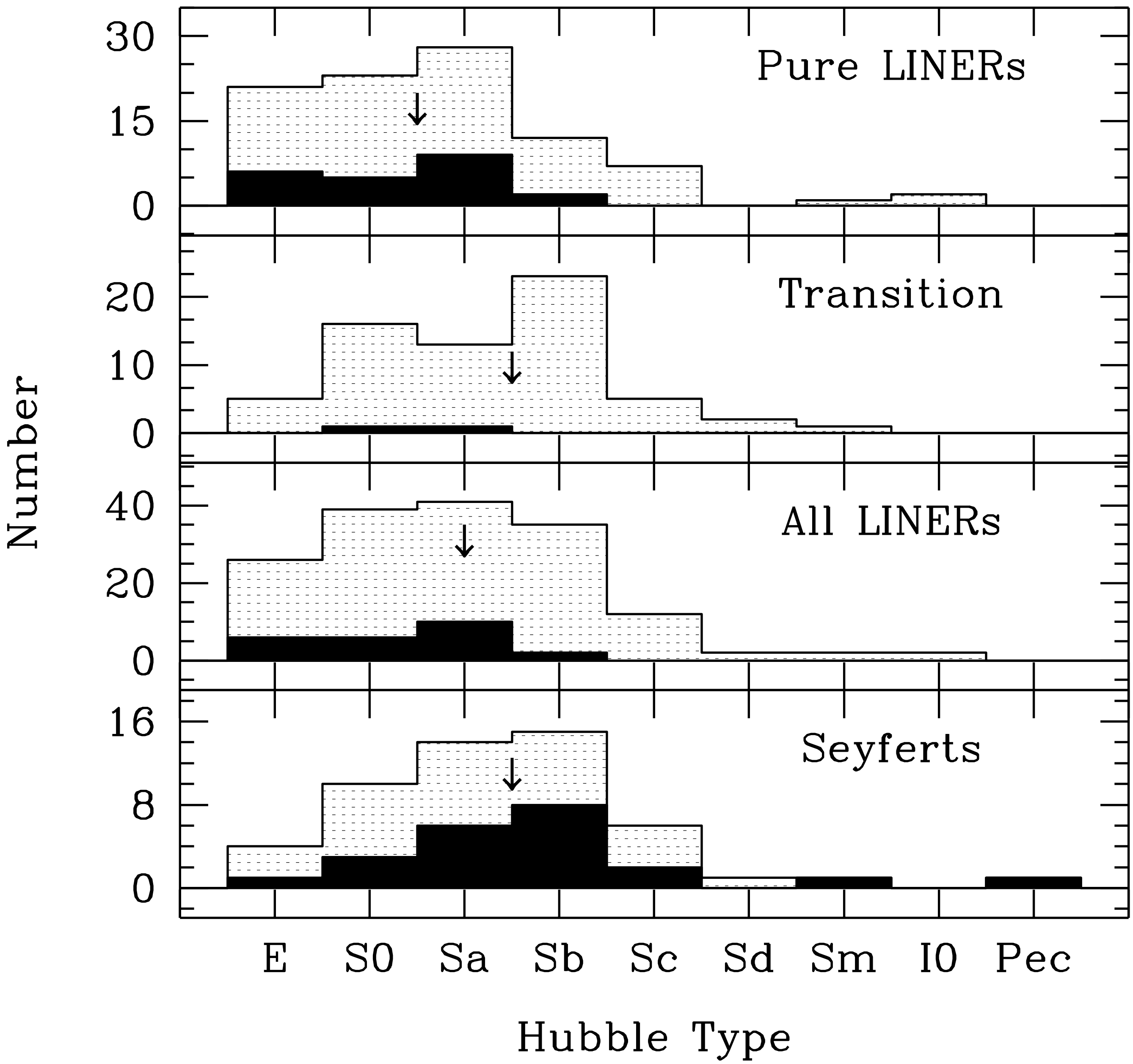
All Emission
H II Nuclei
AGNs
Detection Rate (%)
100
50
0
80
40
0
80
40
0
E
S0
Sa
Sb
Sc
Sd
Sm
I0
Pec
Hubble Type



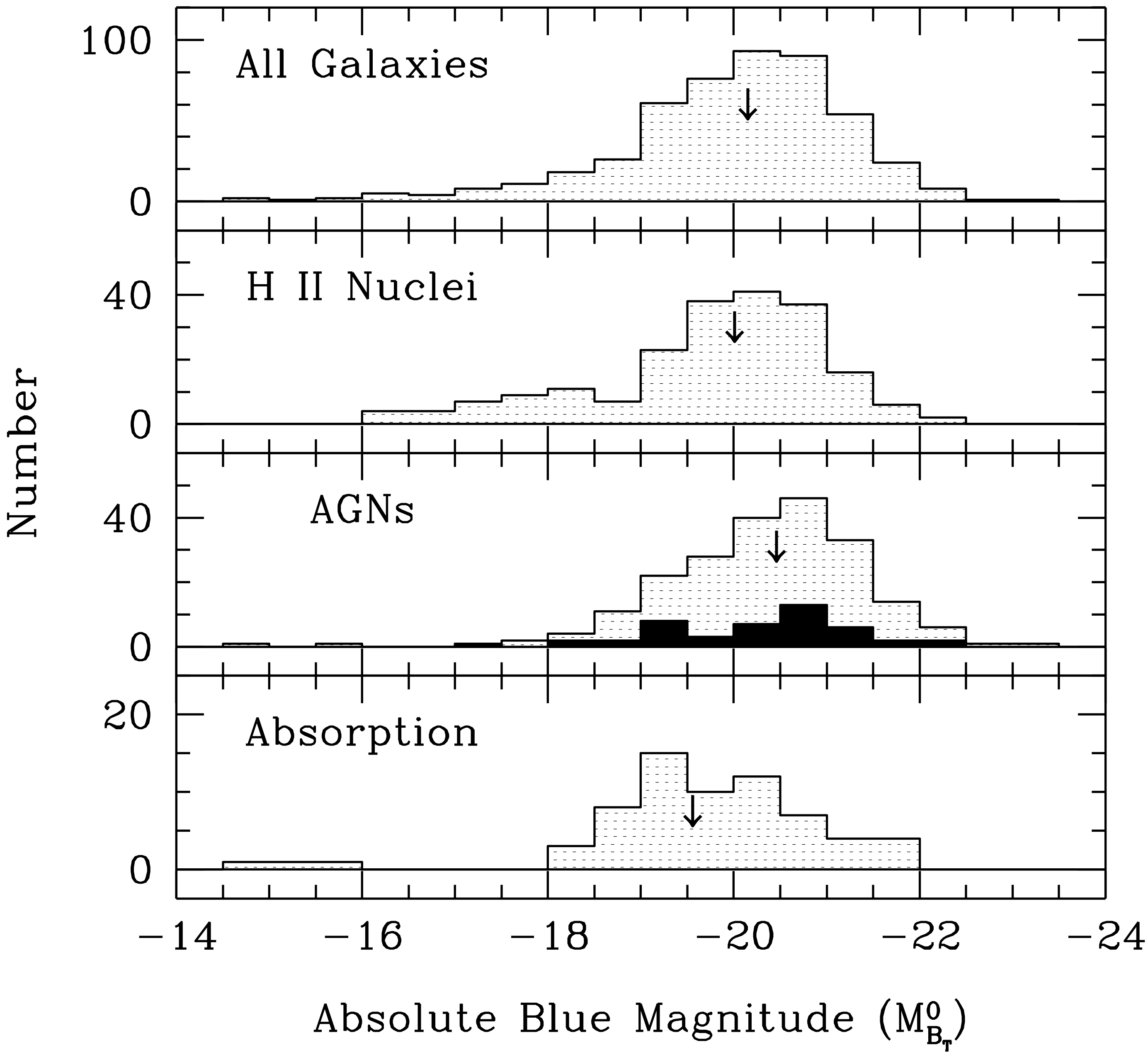
Pure LINERs
Transition
All LINERs
Seyferts
Detection Rate (%)
Hubble Type
E
S0
Sa
Sb
Sc
Sd
Sm
I0
Pec
50
0
25
0
50
0
25
0



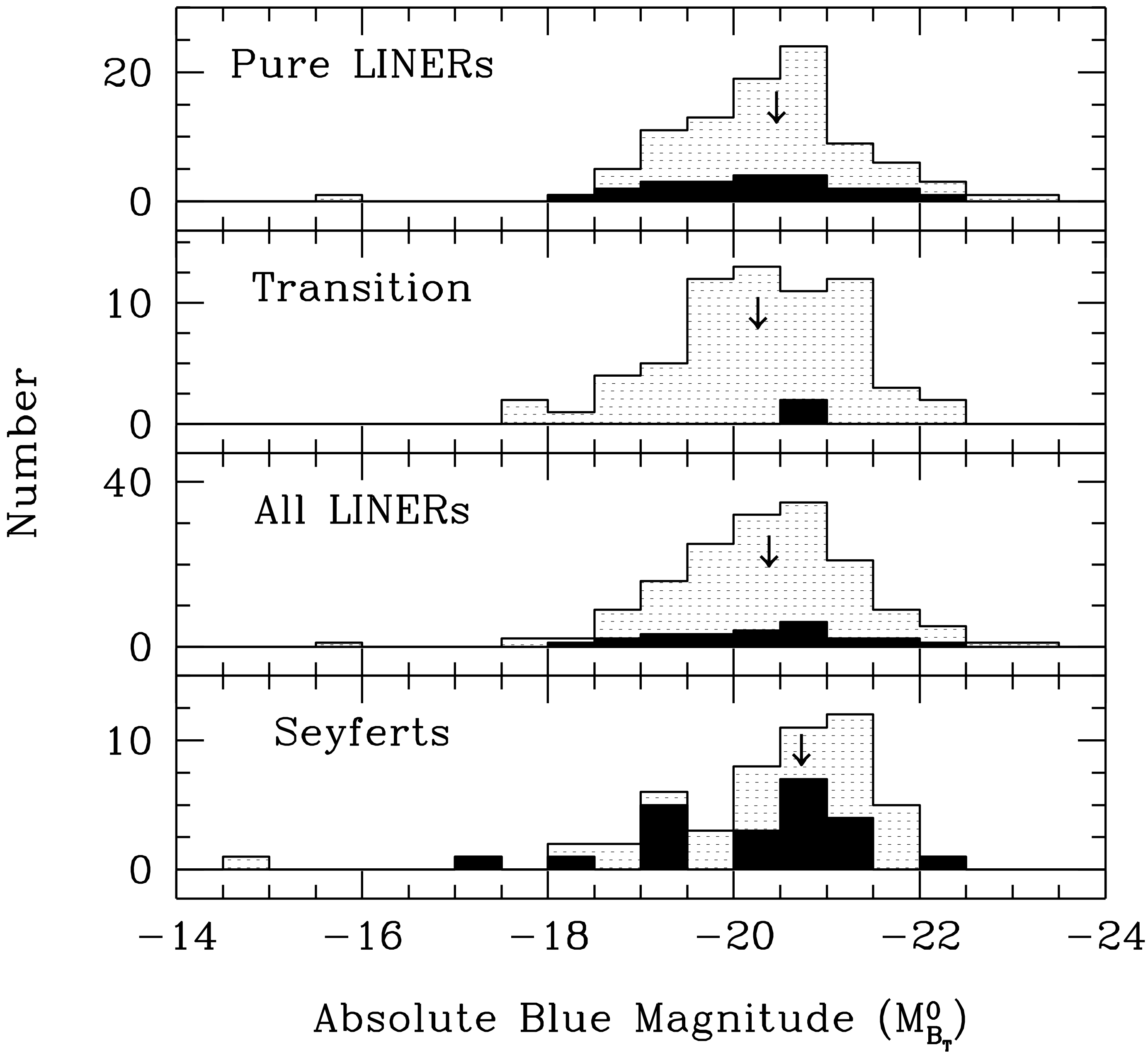
All Emission
H II Nuclei
AGNs
Number
0
40
80
0
40
80
0
25
50
E
S0
Sa
Sb
Sc
Sd
Sm
I0
Pec
Hubble Type



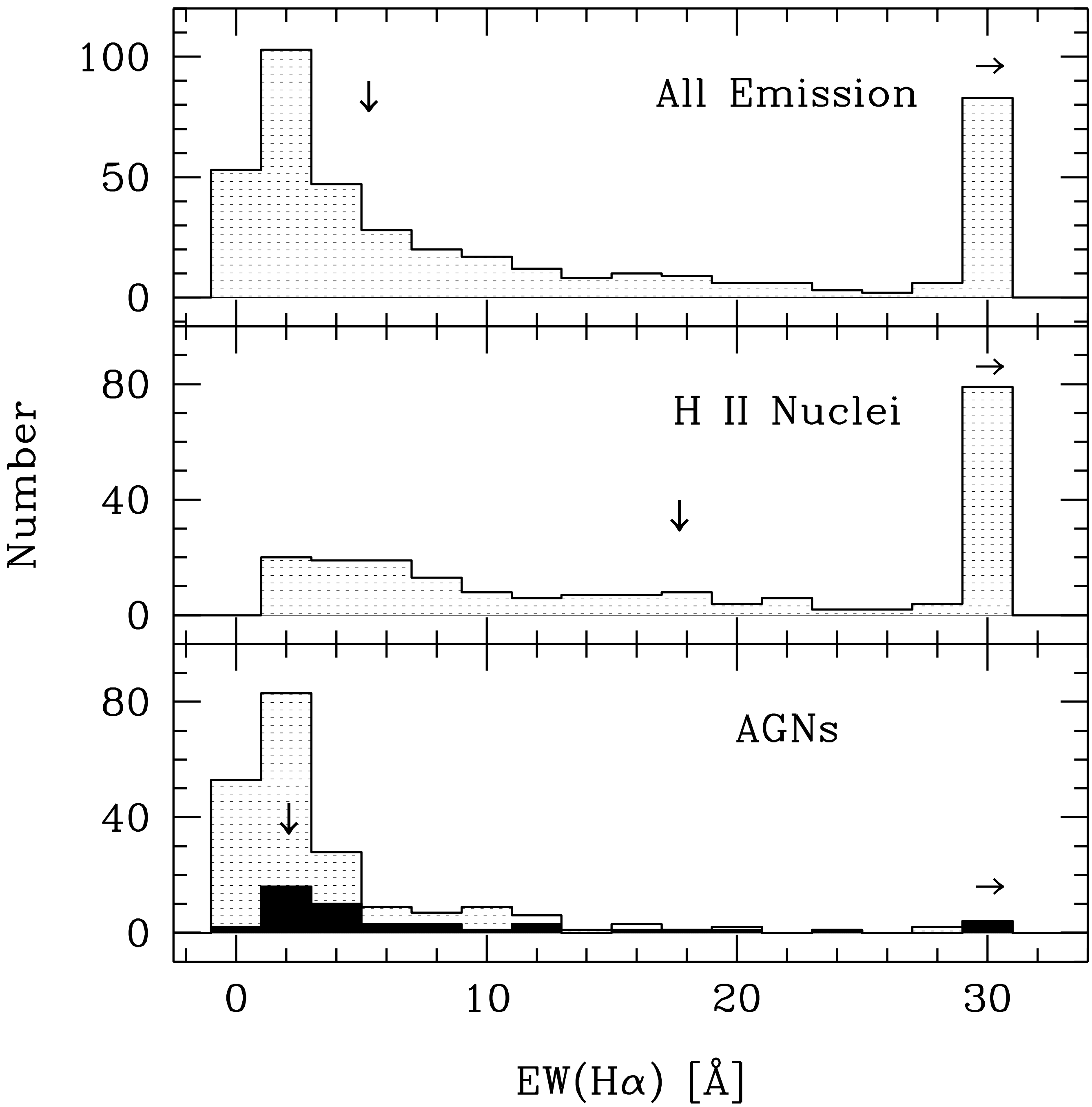
Pure LINERs
Transition
All LINERs
Seyferts
30
15
0
20
10
0
40
20
0
16
8
0
Number
E
S0
Sa
Sb
Sc
Sd
Sm
I0
Pec
Hubble Type

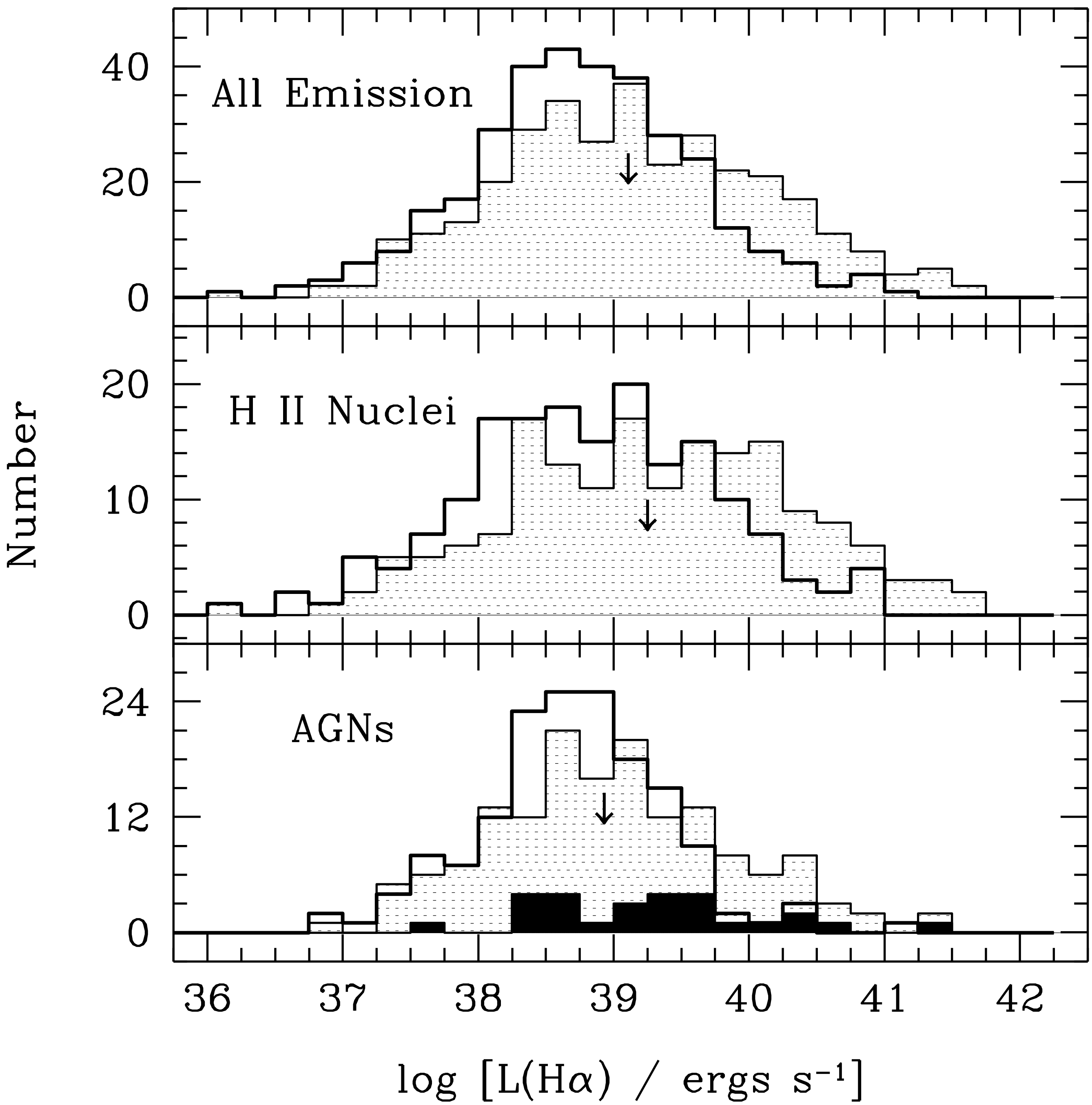


All Galaxies
H II Nuclei
AGNs
Absorption
100
0
40
0
40
0
20
0
Number
−14
−16
−18
−20
−22
−24
Absolute Blue Magnitude ($M^0_{B_T}$)

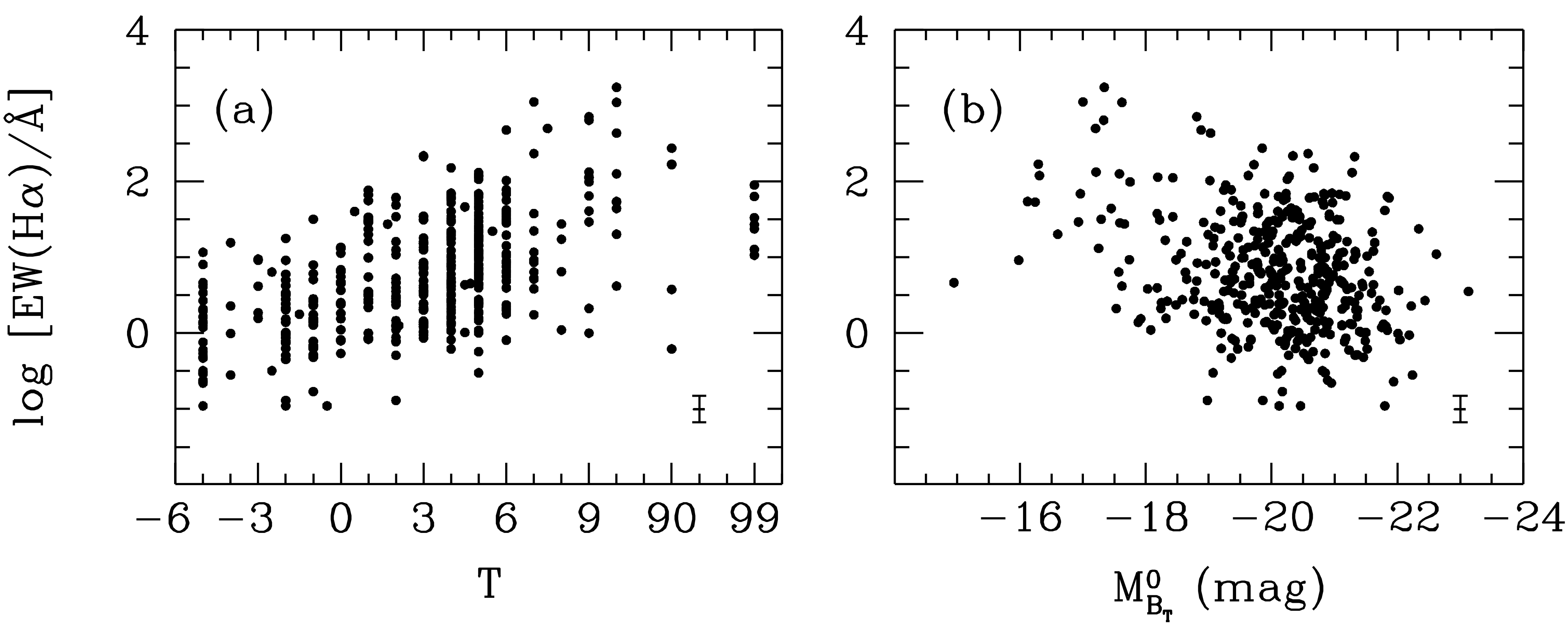


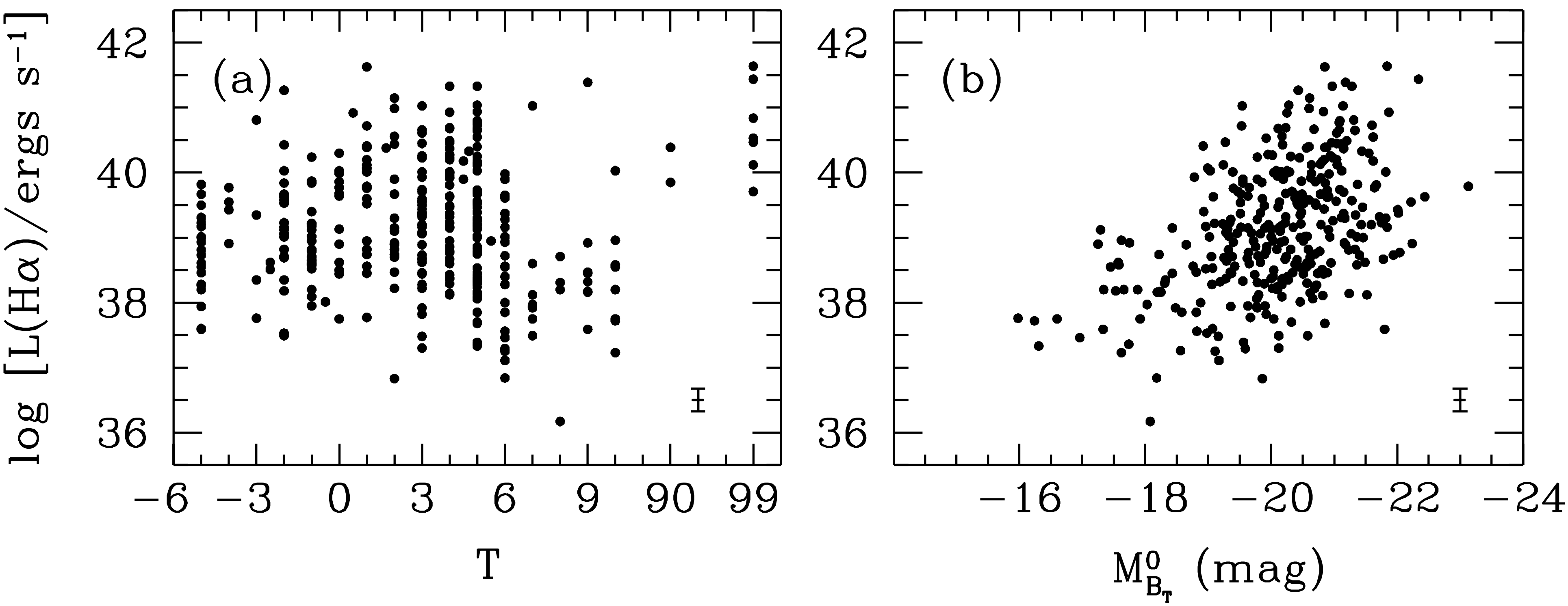
Pure LINERs
Transition
All LINERs
Seyferts
20
0
10
0
40
0
10
0
Number
−14
−16
−18
−20
−22
−24
Absolute Blue Magnitude ($M^0_{B_T}$)

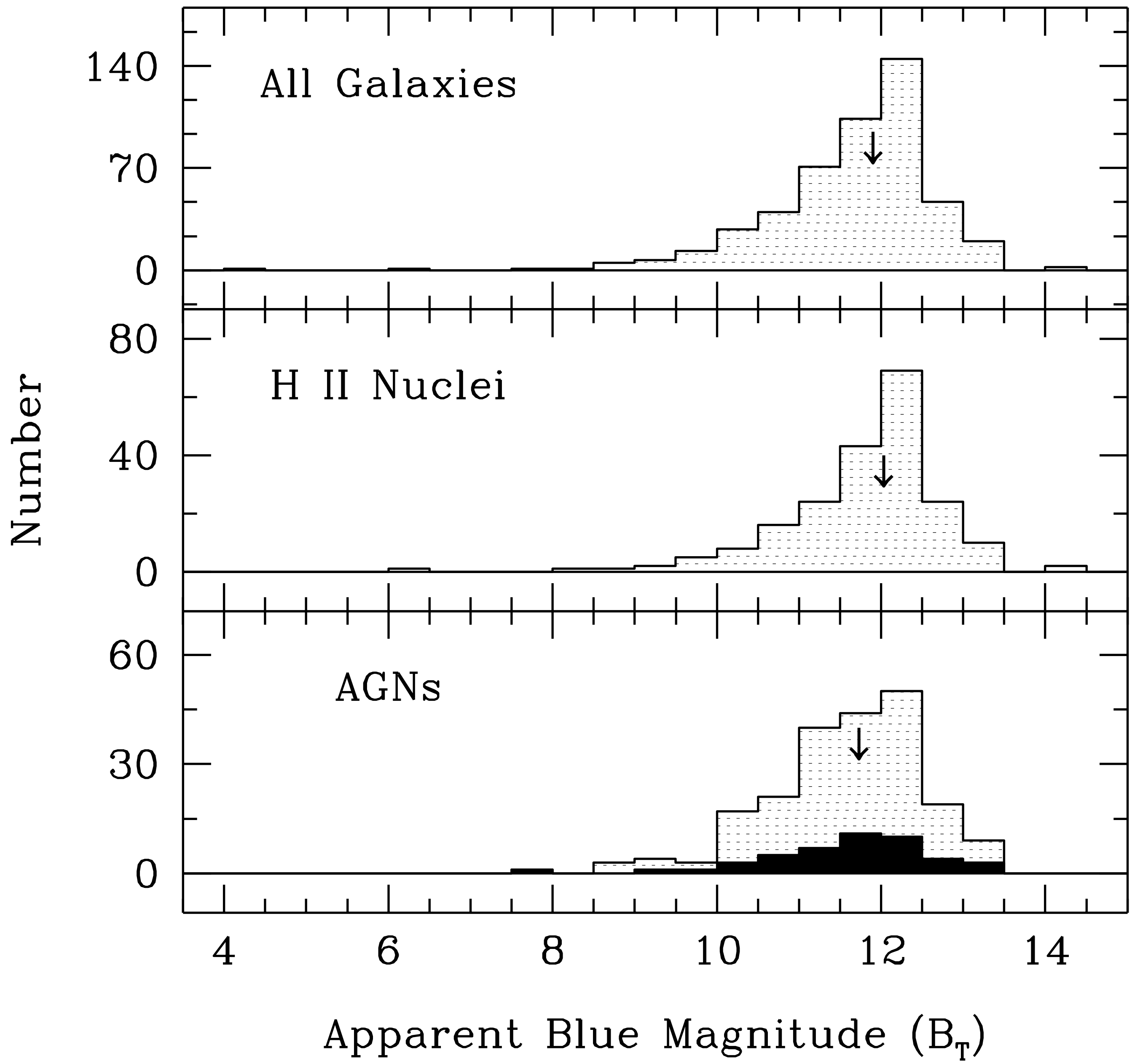

All Emission
H II Nuclei
AGNs
Number
EW(Hα) [Å]
100
50
0
80
40
0
80
40
0
0
10
20
30



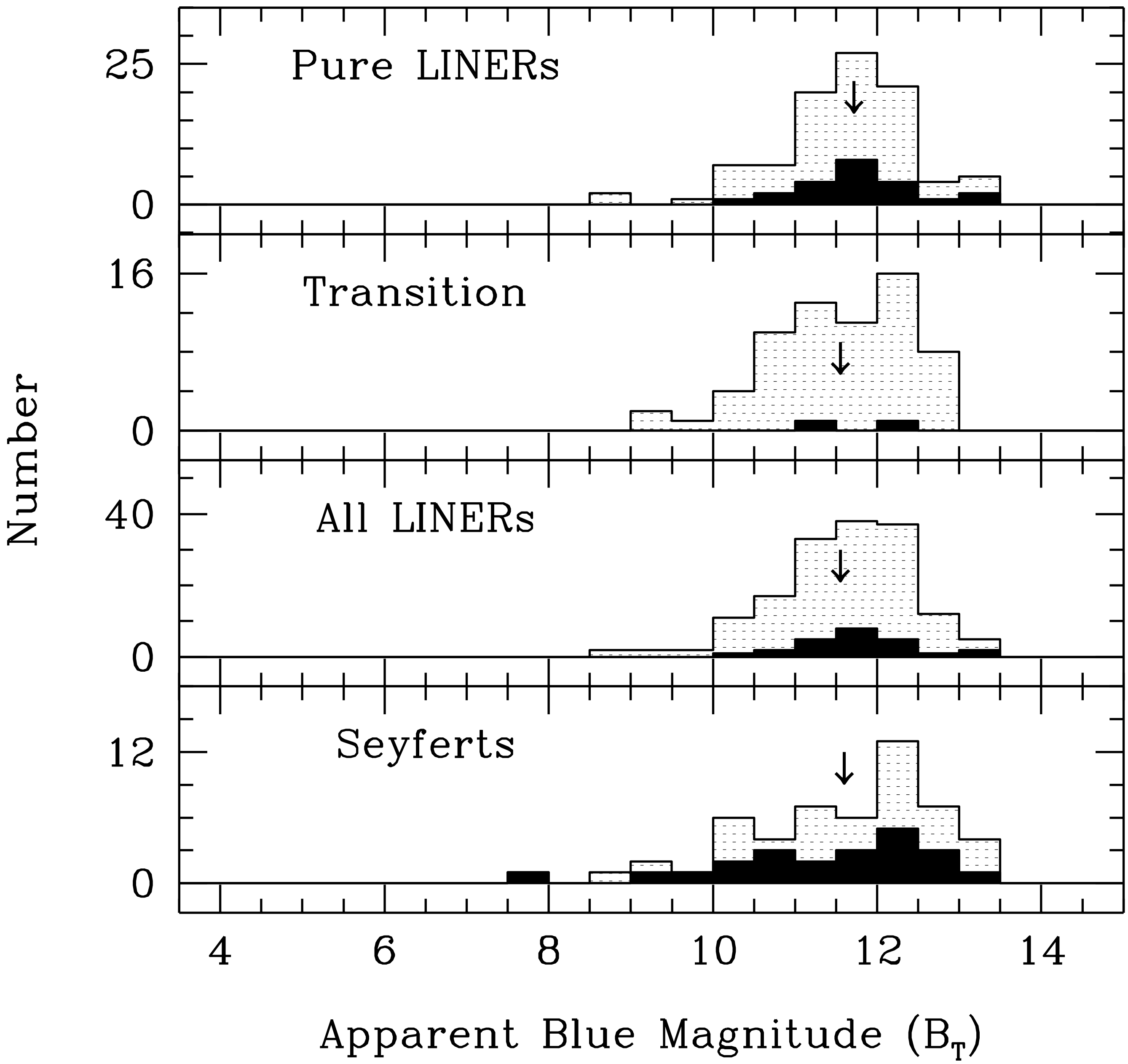
All Emission
H II Nuclei
AGNs
Number
40
20
0
20
10
0
24
12
0
36
37
38
39
40
41
42
log [L(Hα) / ergs s⁻¹]


(a)
(b)
log [EW(Hα)/Å]
4
2
0
−6
−3
0
3
6
9
90
99
T
−16
−18
−20
−22
−24
$M^0_{B_T}$ (mag)

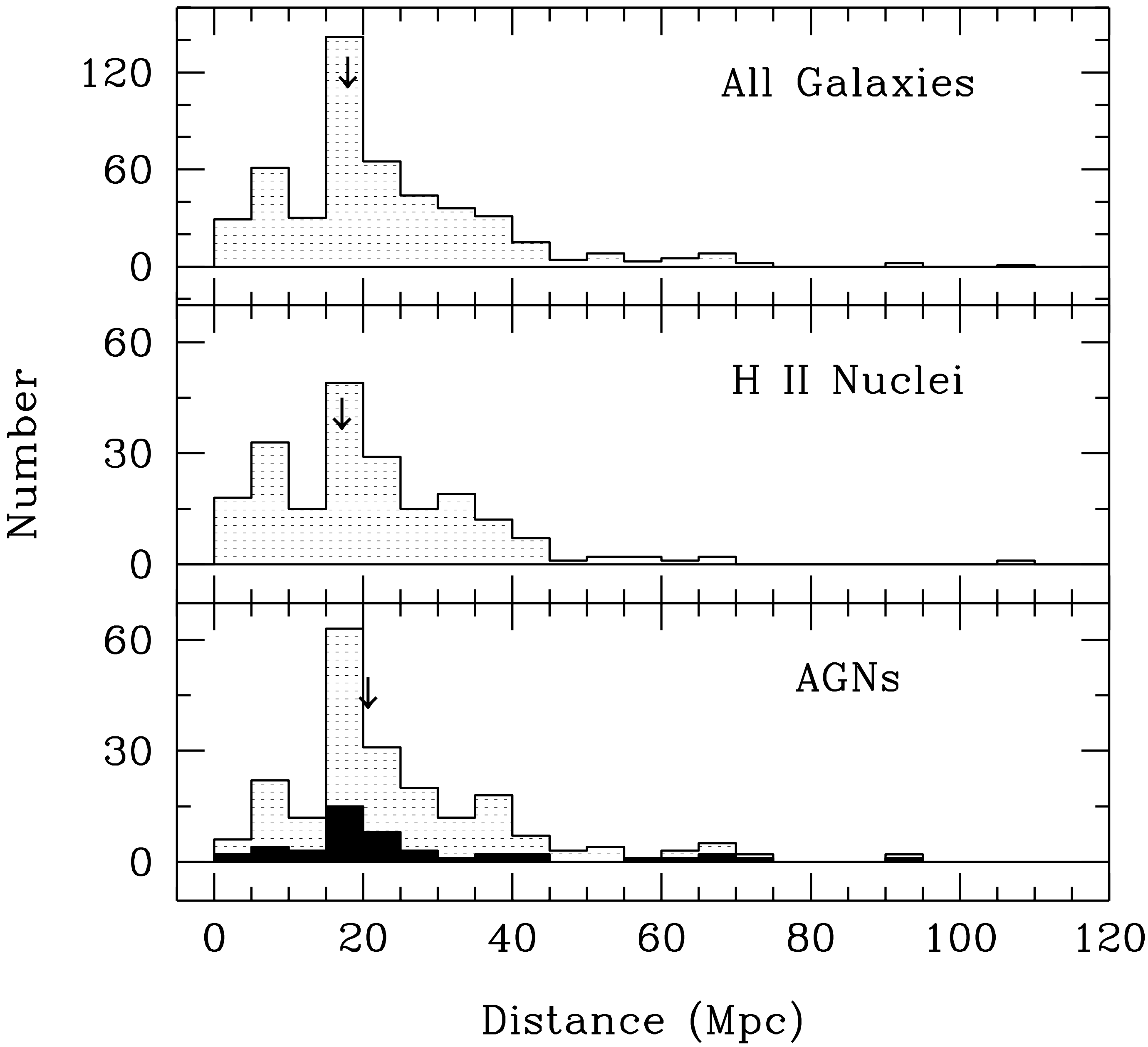

log [L(Hα)/ergs s⁻¹]
42
40
38
36
(a)
−6
−3
0
3
6
9
90
99
T
(b)
−16
−18
−20
−22
−24
$M^0_{B_T}$ (mag)

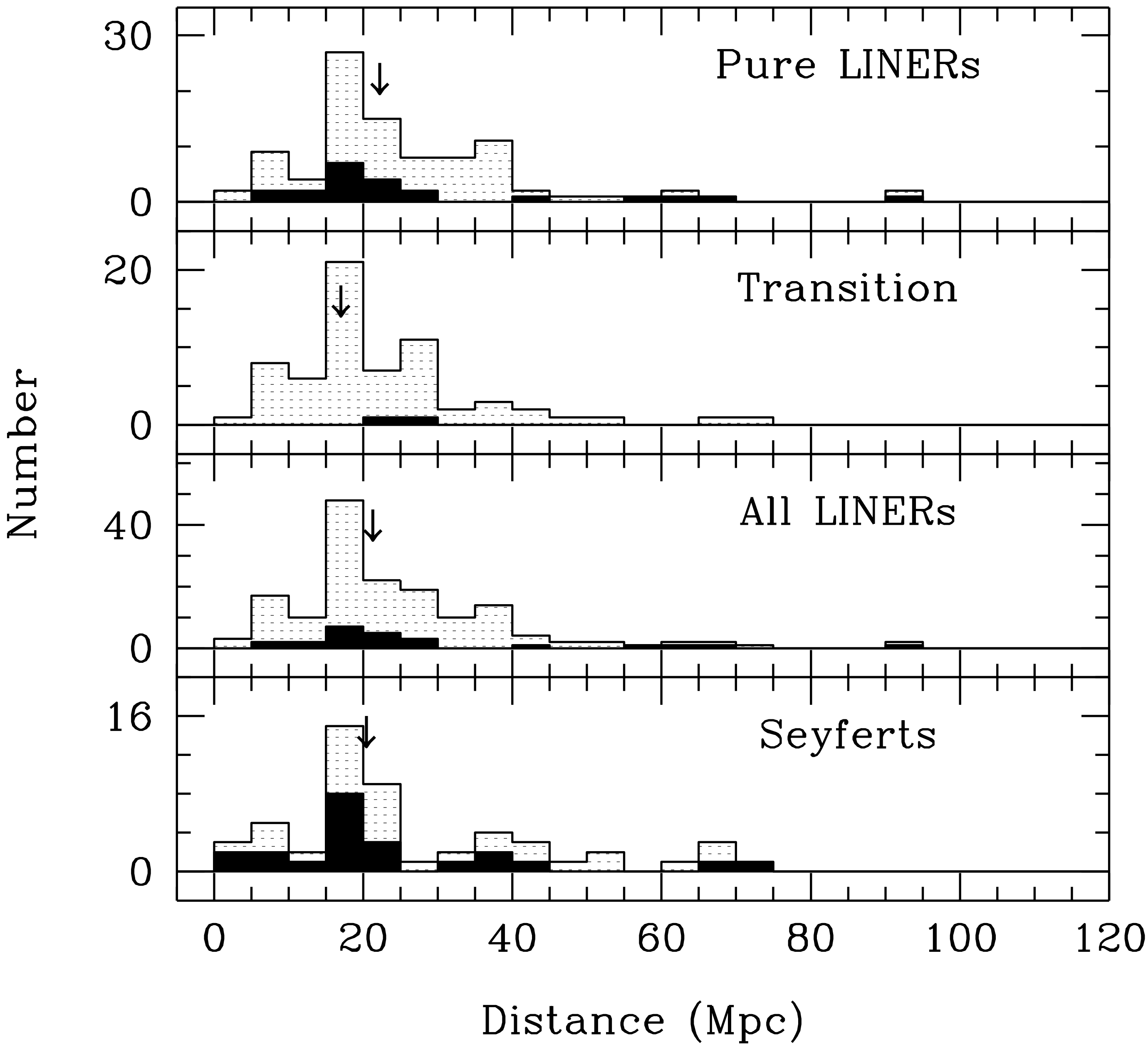


All Galaxies
H II Nuclei
AGNs
Number
Apparent Blue Magnitude (B_T)
140
70
0
80
40
0
60
30
0
4
6
8
10
12
14



Pure LINERs
Transition
All LINERs
Seyferts
Number
25
0
16
0
40
0
12
0
4
6
8
10
12
14
Apparent Blue Magnitude (B_T)


All Galaxies
H II Nuclei
AGNs
Number
Distance (Mpc)
0
60
120
30
0
20
40
60
80
100
120



Pure LINERs
Transition
All LINERs
Seyferts
30
0
20
0
40
0
16
0
0
20
40
60
80
100
120
Number
Distance (Mpc)

TABLE 1
MEDIAN PROPERTIES

Spectral Class	No.[a]	T	No.	B_T	No.	$M^0_{B_T}$	No.	d	No.	i	No.	log L(Hα)	No.	EW(Hα)
All galaxies	471	3.0	486	11.90	486	–20.15	486	17.9	401	52.0	...	...	...	...
All emission	405	3.0	417	11.89	417	–20.22	417	18.9	361	52.0	329	39.11	413	5.3
H II nuclei	197	5.0	206	12.03	206	–20.01	206	17.1	190	53.5	172	39.25	204	17.7
All AGNs	208	1.0	211	11.73	211	–20.46	211	20.6	171	51.0	157	38.93	209	2.1
Pure LINERs	92	0.0	94	11.72	94	–20.46	94	22.2	72	50.0	71	38.82	93	1.9
Transition objects	65	2.0	65	11.72	65	–20.26	65	17.0	55	58.0	48	38.84	64	1.7
All LINERs	157	1.0	159	11.72	159	–20.38	159	21.3	127	52.0	119	38.82	157	1.8
Seyfert nuclei	51	2.0	52	11.77	52	–20.73	52	20.4	44	44.5	38	39.22	52	3.5

[a]Excluding T = "...," 90, and 99 (see Paper III).

Note.—The units are as follows: d = Mpc, B_T = mag, $M^0_{B_T}$ = mag, i = degrees, L(Hα) = ergs s^{-1}, and EW(Hα) = Å.

TABLE 2a

DETECTION RATES OF EMISSION-LINE NUCLEI

Hubble	All Classes		Pure Absorption Nuclei			Emission Nuclei			H II Nuclei			Seyfert Nuclei		
Type	No.	P_g	No.	P_t	P_g	No.	P_t	P_g	No.	P_t	P_g	No.	P_t	P_g
E	57	11.7	26	45.6	39.4	31	54.4	7.4	0	0.0	0.0	4	7.0	7.7
S0	88	18.1	32	36.4	48.5	56	63.6	13.3	7	7.9	3.4	10	11.4	19.2
S0/a–Sab	77	15.8	5	6.5	7.6	72	93.5	17.1	17	22.1	8.3	14	18.1	26.9
Sb–Sbc	103	21.2	1	1.0	1.5	102	99.0	24.3	52	50.5	25.2	15	14.5	28.9
Sc–Scd	109	22.4	1	1.0	1.5	108	99.0	25.7	89	81.7	43.1	6	5.5	11.5
Sd–Sdm	19	3.9	1	5.3	1.5	18	94.7	4.3	15	78.9	7.3	1	5.3	1.9
Sm–Im	21	4.3	0	0.0	0.0	21	100.0	5.0	17	80.9	8.3	1	4.8	1.9
I0	5	1.0	0	0.0	0.0	5	100.0	1.2	3	60.0	1.5	0	0.0	0.0
Pec+S pec	7	1.4	0	0.0	0.0	7	100.0	1.7	6	85.7	2.9	1	14.3	1.9
All	486	100.0	66	13.6	100.0	420	86.4	100.0	206	42.4	100.0	52	10.7	100.0

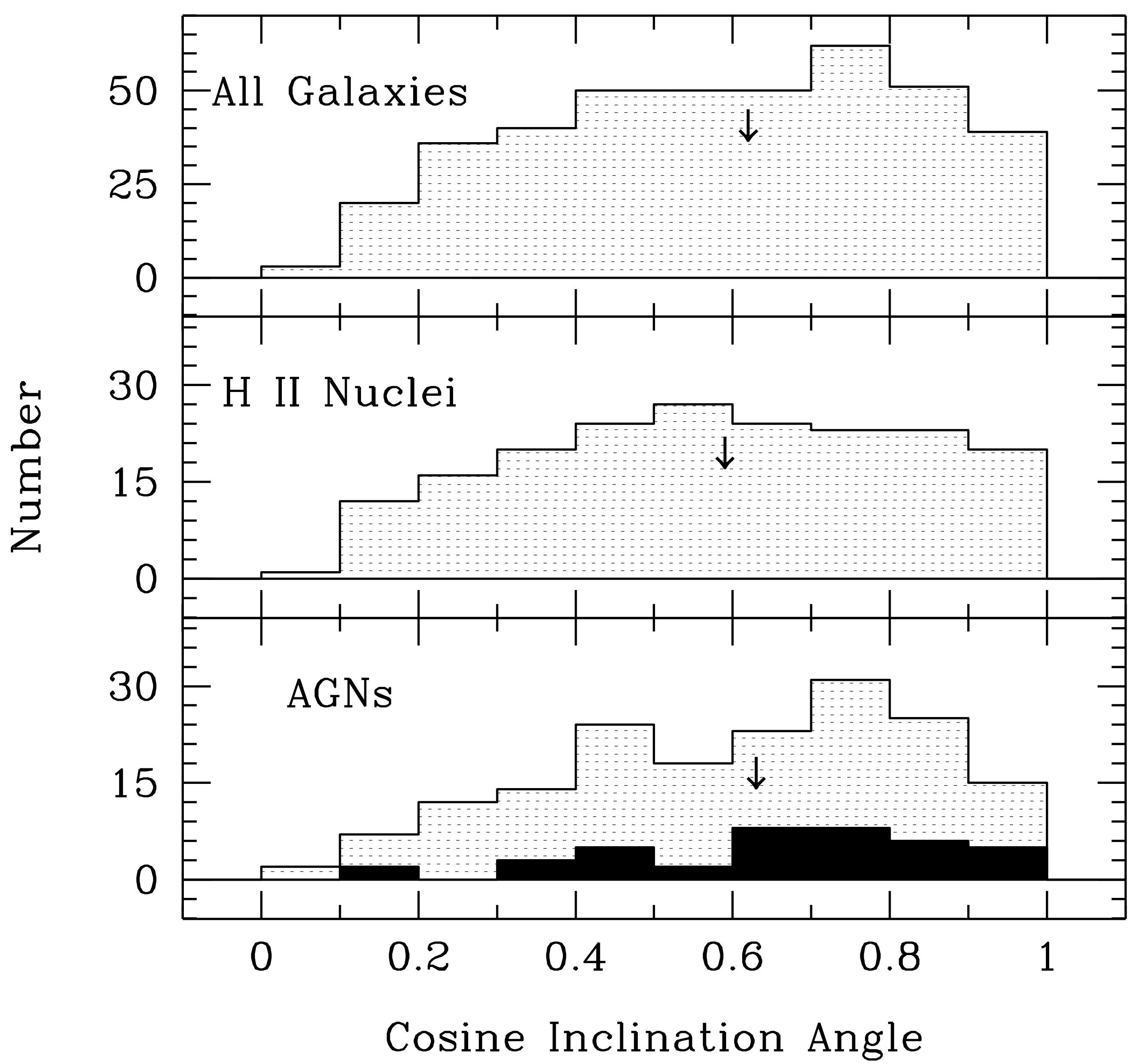
NOTE.—P_t is the percentage of all galaxies of a given Hubble type belonging to a specific spectroscopic class. P_g denotes the percentage of all galaxies of a given spectroscopic class belonging to a specific Hubble type. The sum of all values of P_g in a given class totals 100%.

TABLE 2b

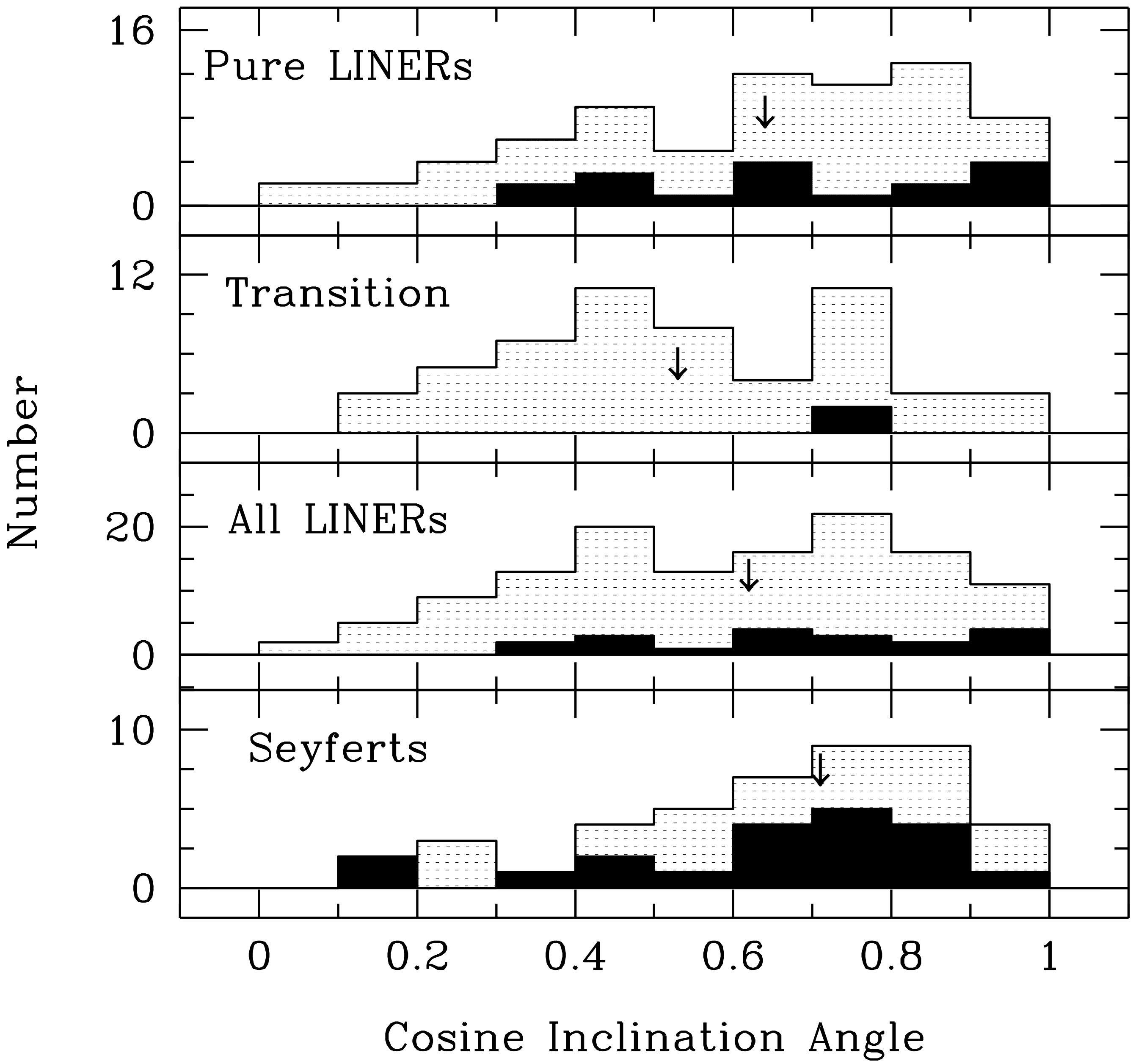
DETECTION RATES OF EMISSION-LINE NUCLEI —*Continued*

Hubble	LINERs			Transition Objects			LINERs+Transition			All AGNs			Type 1 AGNs		
Type	No.	P_t	P_g	No.	P_t	P_g	No.	P_t	P_g	No.	P_t	P_g	No.	P_t	P_g
E	21	36.8	22.3	5	8.8	7.7	26	45.6	16.3	30	52.6	14.2	7	12.3	15.2
S0	23	26.1	24.5	16	18.2	24.6	39	44.3	24.5	49	55.7	23.2	9	10.2	19.6
S0/a–Sab	28	36.4	29.8	13	16.9	20.0	41	53.3	25.8	55	71.4	26.1	16	20.8	34.8
Sb–Sbc	12	11.7	12.8	23	22.3	35.4	35	33.9	22.0	50	48.5	23.7	10	9.7	21.7
Sc–Scd	7	6.4	7.5	5	4.6	7.7	12	11.0	7.6	18	16.5	8.5	2	1.8	4.4
Sd–Sdm	0	0.0	0.0	2	10.5	3.0	2	10.5	1.3	3	15.8	1.4	0	0.0	0.0
Sm–Im	1	4.8	1.1	1	4.8	1.5	2	9.5	1.3	3	14.3	1.4	1	4.8	2.2
I0	2	40.0	2.1	0	0.0	0.0	2	40.0	1.3	2	40.0	0.9	0	0.0	0.0
Pec+S pec	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	1	14.3	0.5	1	14.3	2.2
All	94	19.3	100.0	65	13.4	100.0	159	32.7	100.0	211	43.4	100.0	46	9.5	100.0

NOTE.—P_t is the percentage of all galaxies of a given Hubble type belonging to a specific spectroscopic class. P_g denotes the percentage of all galaxies of a given spectroscopic class belonging to a specific Hubble type. The sum of all values of P_g in a given class totals 100%. The group "All AGNs" represents the sum of Seyferts, LINERs, and transition objects, and "Type 1 AGNs" refers to all AGNs found to have broad Hα emission in Paper IV.



All Galaxies
H II Nuclei
AGNs
Number
Cosine Inclination Angle
0
25
50
0
15
30
0
15
30
0
0.2
0.4
0.6
0.8
1



Pure LINERs
Transition
All LINERs
Seyferts
16
0
12
0
20
0
10
0
0
0.2
0.4
0.6
0.8
1
Number
Cosine Inclination Angle